HAZARDS ASSOCIATED WITH ACCIDENTAL FIRES IN CLINICAL WASTE STORAGE

S.J. Kershaw
Haztech Consultants Ltd, Meridian House, Road One, Winsford Industrial Estate, Winsford CW7 3QG

Clinical waste and group D waste is incinerated throughout the United Kingdom in purpose built incinerators authorised under the Environmental Protection Act 1990, and conditions for incineration are detailed in SI No. 767 The Environmental Protection (prescribed Process and Substances) (Amendment) (Hazardous Waste Incineration) Regulations 1998.

Although generally incinerated upon delivery there is limited temporary storage on site awaiting incineration. The waste potentially contains biohazard material with pathogens present and active pharmaceutical products. There is a risk of fire in this stored material.

A simple theoretical model was developed to assess the contribution of the pathogens and group D pharmaceutically active waste to the toxicity of the fire plume from an accidental fire in the stored material. The method was applied to stored waste at an authorised incinerator site and the study showed the additional hazard of the pathogen biohazard and pharmaceutically active material to be negligible compared to the products of combustion of typical plastic packaging material.

The method could be used to screen other storage installations to indicate the additional risk posed by the type of storage and whether more rigorous fire modelling and or quantification of off site risk are warranted.

Key Words Products of combustion, Fire Risk, fire plume, accidental fire, clinical waste

INTRODUCTION

Clinical waste and group 'D' waste is incinerated in purpose built incinerators authorised under the Environmental Protection Act 1990, and conditions for incineration are detailed in SI No. 767 The Environmental Protection (prescribed Process and Substances) (Amendment) (Hazardous Waste Incineration) Regulations 1998.

The type of wastes accepted for incineration are groups A, B, C, D and E as defined by the Health and Services Advisory Committee HSAC (1). These groups include sharps such as hypodermic needles, surgical tools and glass suitably contained in UN approved packaging. It also includes swabs, dressings and an extremely high proportion of plastic packaging material (up to 40%).

Group 'D' bulk prescription only medicines (POMs) suitably packaged on wooden pallets are also incinerated and these are generally from pharmaceutical companies. These materials are either out of specification, surplus or damaged material and need to be incinerated at a licensed site.

There is limited storage of this material at the incineration site and it is usually processed on the day of arrival. Following a licence application for an incineration site the site was asked to perform a risk assessment on the impact of an accidental fire in this stored material and particularly the potential effect of entrained group 'D' pharmaceutically active waste on the toxicity of the fire plume from an accidental fire.

LEGISLATIVE REGIME

The site has been issued with an authorisation licence under the Environmental Protection Act 1990.

The licence sets out parameters for releases to air from specified release points as part of the authorised process. The process is the incineration of waste in a purpose designed and built incinerator with monitoring and control.

The additional requirement in the authorisation to assess the impact of an accidental fire goes beyond the requirements of the authorised process in that it is requiring the assessment of potential accidents not associated with the process itself but in peripheral storage and their impact on the surrounding environment.

Calculation and determination of the potential impact of fire plumes from accidental fires has generally only been carried out on large warehouses which potentially come under the Control of Major Accident Hazard (COMAH) regulations(2). The COMAH regulations are applicable where sufficient quantities of dangerous material are stored as defined by the threshold quantities in schedule 1 of the COMAH regulations i.e. they are deemed to have the potential to cause a Major Accident Hazard (MAH). The materials and quantities stored at the facility fall short of the threshold quantities in schedule 1 of the regulations. It could be argued that as such analysis and calculation of potential Major Accident Hazards is not required and the fact that the materials and quantities do not trigger the COMAH legislation that the storage is deemed to be low risk and unlikely to be capable of causing a Major Accident Hazard.

However, although not part of the Authorisation, aspects of the process that are not directly regulated by the authorisation are subject to a general condition implied by section 7(10) of the 1990 Act. It is incumbent on the licensee to comply with:

"(10) References to the Best Available Techniques Not Entailing Excessive Cost, in relation to a process, include (in addition to references to any technical means and technology) references to the number, qualifications, training and supervision of persons employed in the process and the design construction, lay-out and maintenance of the buildings in which it is carried on:"

It is therefore reasonable to require an assessment of the controls and measures put in place to prevent the occurrence of fire in the building in which the prescribed process is carried on and the potential impact of a fire occurring on the surrounding environment.

RISK ASSESSMENT

At the outset there is a need to determine the depth of risk assessment and whether to use a Qualitative Risk assessment. The value of this approach is that it is formal, documented and it may be all that is needed to make decisions on whether a risk is ALARP (As Low As Reasonably Practical) by comparing with standards and other operations that are generally accepted as tolerable risk. Decisions are effectively **'technology based'** - satisfactory risk control is achieved when relevant best or good practice is adopted or harm is not feasible. The alternative would be to use a Quantitative Risk Assessment technique with '**Equity based'** decision making criteria – in that people and environment have unconditional rights to certain levels of protection i.e. define the maximum level of risk. This would be In terms of a level of a numerically determined risk to which individuals on and off site should not be exposed.

Reviewing the toxicity of the material stored there were no materials which carried 'Risk Phrases','R' catagories or named substances that are noted in schedule 1 of the COMAH Regulations(2). Some of the materials and active pharmaceuticals may have Control of Substances Hazardous to Health, COSHH assessments and occupational exposure limits determined. COSHH assessments are valuable for the safe handling of materials and protection of workers from long and short term exposure during normal use and operation and also abnormal exposure such as spill or other accidental loss of containment. However these COSHH assessments are of little help in assessing the risks associated with accident hazards such as large fires which can potentially release significant quantities of materials at temperatures and conditions that would not be expected in forseeable normal or forseeable abnormal use of the material.

In assessing the maximum quantities stored there are a number of storage zones as shown in Table 1.

Table 1. Material Storage

	PALLETS	WEIGHT	HC KJ/kg	Wood Equiv Kg
Zone 1				
Group D POMs	75	30000	25000	45,454.5
Waste on floor	50	20000	25000	30,303.0
Total Zone 1				75,757.6
Zone 2				
Waste on Mezzanine	50	20000	25000	30,303.0
Waste in pit		16000	17000	16,484.8
Total Zone 2				46,787.9

The maximum storage in zone 1 is 75,757 kg of wood equivalent material and in zone 2 46,788 kg. The heat of combustion for a kg of the waste in different locations was estimated and the weight of material in that area converted to a wood equivalent based on the typical heat of combustion of wood. Comparing this quantity of material to a small warehouse such with perhaps 1000 tonnes of plastic goods or foamed furniture the quantity of plastics and material for combustion is relatively small.

For the active pharmaceutical or pathogens to be a higher risk or hazard compared to a warehouse containing relatively common combustible commodities would need the contribution of the pathogen or pharmaceutical in the fire plume to be significantly more toxic or in greater abundance that the toxic species that are generated by the combustion of common combustible materials typically present in general warehousing and storage facilities.

Following this premise the following areas were considered

- ☐ Toxicology of fires in common combustible material
- ☐ Classification of materials stored on site in terms of toxicology for different wastes stored.
- ☐ Assessment of potential hazards associated with accidental fires in these different materials and comparison with Toxicology of fire in common combustible material. At this stage the hazard may be shown to be either significant and requiring more detailed

analysis or the additional hazards associated with a fire involving the waste material compared to a normal fire to be negligible in which case further analysis would not be required.

TOXICOLOGY OF COMMON PRODUCTS OF COMBUSTION

The smoke generated by accidental fires in standard combustible material such as cellulosic material (wood, paper cardboard) and plastics that are used in packaging, construction and furniture contain a number of toxic species. These toxic species are generated from the combustion of the material and depend on the chemical formula and composition of the original material, the temperature of combustion and the level of oxygenation of the fire. Typical species in a fire plume and conversion from the elements in the original fuel are shown in table 2.

Table 2 – Typical Smoke Species for Standard Combustible Material

Material	Fire Species Conversion
Carbon (C)	Carbon Monoxide (CO)
Carbon (C)	Carbon Dioxide (CO_2)
Nitrogen (N)	Nitrogen Dioxide (NO_2)
Nitrogen (N) & Hydrogen (H)	Hydrogen Cyanide (HCN)
Chlorine (Cl) in plastics	Hydrogen Chloride (HCl)

These species in a fire plume are highly toxic in the concentrations found in domestic and industrial fires and are the main cause of fatality in the majority of accidental fire cases. This is a result of groups or individuals being either trapped in a building on fire or overcome while asleep in a dwelling or hotel, which is on fire, and they are unaware of the fire and risk to themselves. Over two thirds of fatalities are the result of smoke inhalation from UK fire statistics in 1987 (3) and this is typical for other years.

For fatality or serious injury to occur from normal domestic or industrial fires would generally require direct inhalation and an inability to escape the fire plume such as being trapped or incapacitated or unaware or the fire.

This assessment is aimed at determining the risk associated with the survival of pathogens and pharmaceutically active material in the fire plume. It is possible to assess all possible smoke species and compare the toxicity to the surviving material and all species generated from the products of combustion of the pharmaceutical material. However, the proportion of chlorine in the pharmaceutical material is reported to be extremely low in comparison with the packing material and plastics and the assessment is aimed at providing a quick reference to see whether the risk is greater than for normal combustible material.

Extensive investigations examining human fire fatalities with respect to exposure to toxic atmospheres have shown carbon monoxide to be the primary toxicant(4)(5) . Hydrogen cyanide is also produced and is 300 times more toxic than carbon monoxide but as experience has shown the carbon monoxide usually predominates in terms of the toxicity of the fire plume because of its abundance. It would therefore be reasonable to assess the toxicity of entrained pharmaceutical or pathogen in comparison to carbon monoxide as an indication of the relative risk of an accidental fire involving the stored material. If a material were being stored with an extremely high proportion of nitrogen, nitrile or cyanide species then it would be prudent to review the HCN being produced. This is not the case in the pharmaceutical storage case.

The proportion of carbon converted to carbon monoxide in an accidental will depend on the level of oxygenation in the fire, which is a factor of the ventilation rate. In a confined fire the composition of the fire plume can range from negligible at the onset to over 10,000 ppm at flashover in a confined room. Studies on conversion factors by TNO laboratories(6) for a number of typically stored chemicals gave conversion factors of up to 9.7% of the carbon to carbon monoxide. Therefore a reasonable estimate would be to use 5% as a conversion factor.

TOXICOLOGY OF CLINICAL WASTE

This will include group A, B, C, and E wastes and arrives in yellow bags and UN approved packaging. The majority of this material may contain dressings, bedpans, organic matter, etc. which may have blood and body fluid contamination. There will be an amount of sharps that may have traces of prescription only medicines on them but this is negligible when considering the majority of this type of waste. The potential hazard associated with the waste is defined by its biohazard properties linked to pathogens that may be present in the body fluid contaminated material.

The main risk to an individual from this waste is transmission of a pathogen by direct contact with the bodily fluid and direct inhalation or transmission to the blood stream by accidental incision, puncture wound or direct contact with abraded skin (7). As such the main risk is to the operators handling the material.

Products of combustion of the pathogen itself is not an issue, if it is combusted to produce products of combustion it will not have infectious properties. To remain a potential hazard the pathogen involved will need to be hazardous by airborne transmission and survive the fire plume and be breathed in sufficient dose to be infectious.

The typical bacterial pathogens found in clinical waste are not airborne pathogens and are inactivated at generally low temperatures. As an indication bed linen which is often contaminated with the same typical pathogens as in the waste is required to be washed at 80°C for 1 minute or 70°C for 3 minutes, there is also some light detergent used but this does not in itself have strong anti-bacterial properties. Laboratory testing with test pieces contaminated with heat resistant bacteria have shown this to be effective (7).

The centre line temperature of a developed fire plume is typically 600°C to 800°C and turbulent. For a pathogen to survive would need it to be introduced on a fine powder or in an aerosol which could be introduced at the very edges or top of the fire plume. The clinical waste is packaged in sealed bags and the pathogen is likely to be either on wet or dry dressings or swabs etc. To become airborne would require a fire to rupture the bag, the heat being sufficient to vaporise the water or body fluids sufficiently to carry off the pathogen. To vaporise water in a fire plume is likely to need temperatures in excess of 80°C resulting in a high probability of inactivation of the pathogen. Even if entrained it is then highly likely to be heated in the fire plume above a temperature where it would be destroyed. If the pathogen were on dry dressings or swabs it would require the destruction of the swab in the fire to micron sized particles containing a pathogen, to make it respirable, which would have an extremely high probability of destroying the pathogen. If large sections of material were lifted into the fire plume it would not pose a respirable carrier risk. Taking all these factors into account the risk of infection from accidental fires in clinical waste would appear to be remote.

This qualitative assessment cannot rule out 100% that there is absolutely no risk whatsoever of a pathogen surviving an accidental fire in the clinical waste in some combinations of unforeseen circumstances but in terms of infection and risk to people the risk is seen as vanishingly small compared to the accepted risks associated with handling this material on a day to day basis(7).

TOXICITY OF THE FIRE PLUME THE EFFECT OF ENTRAINED GROUP D WASTE

From work on agrochemical warehouse fires (8) the risks have been determined for survival fractions of the original material intact in the fire plume, products of total combustion and partial break down products of the material. In a fully developed well-oxygenated fire the majority of the material is completely combusted, there will be small and varying amounts of intermediate products depending on combustion conditions (9). The majority will be completely combusted to the product species in Table 2. There will be a small proportion that is entrained in the fire plume. The building is a large open structure and it is unlikely that the fire would be ventilation controlled in its initial phase and so complete combustion would be more likely. Typical analysis and experimentation, (8), (9) have taken 10% of the original parent material to be seeded into the fire. This is a pessimistic assumption in this case.

Atkinson(9) indicates that in a well-ventilated fire the proportion of original material surviving the fire plume depends upon orientation and position of it in the flame. Where the material is introduced at the base of a flame there is almost total destruction of the parent material, where it is introduced towards the top of the flame there is a higher proportion surviving (up to 10%). The analogy is drawn that where there is racking of storage in a warehouse products on higher racks may be involved in the upper regions of a flame and there will be a shorter residence time in the flame and hence less of the original material will be destroyed. In terms of the storage at the site in question it is simply pallets one or two high, block stacked, there are no rack systems for storage and so any material introduced to the fire is likely to be introduced at or near the source of the fire or base of the flame and result in almost total destruction of the parent material. Even though this is the case it has been assumed that 5% of the parent material survives the fire.

POTENTIAL PRODUCTS OF COMBUSTION IN THE FIRE PLUME

The group D pharmaceutical waste is generally organic. There is a high proportion of plastic packing, wooden pallets and cellulosic/organic material. An initial assessment to provide an indication of the potential additional risk of pharmaceutical material seeded into the fire plume can be determined by the proportion of toxic species produced from the packing material and the proportion of the parent pharmaceutical seeded into the fire plume unchanged. The relative toxicity or potential dose can then be compared.

The proportions of packing and products vary. A reasonable estimate for the make up of a pallet of pharmaceutical would be:

Pallet Make Up	
Plastic packing (PVC)	25%
Cellulosic packing, wooden pallet	10%
Pharmaceutical product	65%

It is assumed that all the PVC and cellulosic packing will be combusted and there will be 5 percent of the organic pharmaceutical product entrained into the fire plume. Although many pharmaceutical products that are stored and then incinerated are in preparations and contain excipients some are pure active ingredients in containers. To obtain a worst case the above 65% pharmaceutical product which makes up a pallet assumes it is 100% pure active ingredient.

Assuming 1kg of stored material there will be:

Make up in 1kg	**kg**
Plastic (PVC)	0.250
Cellulosic packing	0.100
Pharmaceutical product combusted	0.6175
Pharmaceutical product entrained in fire plume	0.0325

Where there are complex organic materials with chlorine and other species present there is always a potential for intermediate break down products to be formed in uncontrolled accidental fires. From past work on the risk of fire from an agrochemical warehouse it has been assumed that the toxicity of the surviving fraction is used to calculate risk(8) and so these intermediate species were discounted for this study. In this the case for a first estimate the products of combustion for organic pharmaceutical can be grouped with the cellulosic material

Fire Load Composition	**kg**
Plastic (PVC)	0.250
Cellulosic packing and pharmaceutical organic	0.7175
Pharmaceutical product entrained in fire plume	0.0325

A large proportion of the toxicity of the fire plume will be from the HCl produced from the PVC plastic and CO generated in the smoke plume. In addition there may be plastics other than PVC and there may also be bromine and nitrogen atoms associated with the other plastics and pharmaceuticals which could generate HBr, HCN and NOx. As we are really concerned with the toxicity and effect of the surviving fraction of pharmaceutical it is reasonable to assess the toxicity of the HCl and CO produced in a fire from 1kg as representative of the toxicity of the products of combustion compared to the pharmaceutical surviving unchanged in the fire plume. Further analysis may be valid if it is taken further.

Tables 3, 4, 5 and 6 are taken from a linked spreadsheet which calculates the proportion of species generated in the fire plume when 1kg of the stored material is burned. Table 3 is the input table. The weight of the different components per kg stored is put into Table 3 along with the numbers of atoms making up the material. The calculation of conversion is done in the subsequent tables with Table 6 sowing the weight of the products of combustion formed and pharmaceutical entrained unchanged per kg of stored material burned. Table 6 also converts the mass to a proportion relative to the amount of pharmaceutical entrained.

Table 3 Input of material per kg burned and atoms constituting the material

Material	State	C	H	O	N	S	Cl	F	Br	Mol Wt	Wt of Material per kg	Hc 10xe7 J/kg	Wood Equivlnt kg
		0		0	0	0	0	0	0	0	0	0	0
PVC	Packing	4	6	0	0	0	2	0	0	124.988	0.25	2.86	0.43
Cellulose/ organic	Comb solid	6	10	5						162.14	0.7175	1.65	0.72
Pharmaceutical surviving unchanged in fire plume											0.0325	0	0
Total											1		

Table 4 Atoms burned per kg

Material	State	C	H	O	N	S	Cl	F	Br	Mol Wt	Wt of Material in 1 kg
										0	
PVC	Packing	0.10	0.01	0.00	0.00	0.00	0.14	0.00	0.00	124.988	0.25
Cellulose/organic	Comb solid	0.32	0.04	0.35	0.00	0.00	0.00	0.00	0.00	162.14	0.7175
										0	
Total kg		0.41	0.06	0.35	0.00	0.00	0.14	0.00	0.00		0.9675
Check											0.9675

Table 5 Intermediate calculation

Element	Mass In fire plume Kg per kg burned
C	0.4150
Cl	0.1418
Pharm entrained	0.0325

Table 6 Products of combustion per kg burned

Products of Combustion	Product Kg per kg burned	Proportion relative to entrained Pharmaceutical
CO2	1.447552	44.54
CO	0.04839	1.49
HCl	0.146196	4.50
Pharmaceutical surviving unchanged in fire plume	0.0325	1.00

TOXICITY

Toxicity of airborne materials such as the products of combustion or airborne pharmaceuticals and pure gases is dependent on the concentration in the inhaled air and the duration of exposure. The concentration required to deliver a 'Dangerous Dose' to a human being is described as the 'Dangerous Toxic Load' **(DTL)**. And is expressed as

$$C^{n}t = k \qquad \text{(I)}$$

where C is concentration (ppm), t is time of exposure (in 30 minutes) and n is a power function. This DTL is broadly equivalent to the $LD_{1\text{-}5}$ which is the Lethal Dose expected to give a 1% to 5% fatality for the population exposed. For the carbon monoxide and HCl these are well defined and given in Table 7.

Table 7 – Typical Smoke Species

Material	**Fire Species Conversion**	***n* value**	***k* (ppm^{n}.30min)**
Carbon (C)	Carbon Monoxide (CO)	0.7	3,600
Chlorine (Cl) in plastics	Hydrogen Chloride (HCl)	1	23,730

The above data is well reported and is for inhalation risk. The data that is available for the pharmaceutical products are oral ingestion based in terms of LD50 for mice or rats. The effect of inhalation toxicity can be derived from such data to give an indication of the inhalation risk by following methods by Turner and Fairhurst(10) based on the LD_{50} concentration for the most sensitive species, assuming the $LD_{1\text{-}5}$ for humans is ¼ the LD_{50} for the other species and assuming a 70kg individual and that the average volume of air breathed in 30 minutes is 0.625 m^3.

From a review of all the pharmaceutical material likely to be stored and incinerated the most toxic pharmaceutical oral LD_{50} was 1,470mg/kg

Therefore the concentration in air required to give a **(DTL)** is:

$$C\text{mg/m3} = 1{,}470 \times 70/ (0.625\text{x}4) \qquad \text{(II)}$$

$$\mathbf{= 41{,}160\ mg/m^3}$$

However this is in different units to data available for the products of combustion. Table 8 converts the concentration from DTL in ppm to give DTL in mg/m^3 .

Table 8

Species	***k*** **(ppm^n.30min)**	**Conc to give DTL ppm**	**Conc to give DTL mg/m3**	**Relative toxicity Of species**
HCl	3,600	791.00	1,201	34.3
CO	23,730	933.81	1,088	37.8
Pharmaceutical			41,160	1

Table 8 shows the relative respirable toxicity of the products of combustion compared to the active ingredient in the pharmaceutical. However the relative toxicity in the smoke plume will depend on the proportion of each material in the plume. This is calculated in Table 9 from data in Table 6 and Table 8:

Table 9 Relative toxicity of products of combustion to pharmaceutical entrained.

Material in plume	**Proportion in plume relative to entrained pharmaceutical**	**Relative toxicity Of species**	**Overall relative toxicity in plume**
HCL	4.50	34.3	154
CO	1.49	37.8	56
Pharmaceutical	1.00	1	1

SUMMARY & CONCLUSIONS

The proportion of toxic products of combustion such as carbon monoxide and hydrogen chloride generated from the plastic packing and other combustible material would produce species in the fire plume which are between 56 and 154 times more toxic than the proportion of pharmaceutical entrained into the fire plume. As such the additional toxic risks of a fire from storing this group D material is low compared with the risks associated with general storage. As a result a formal fire review was carried out to ensure the fire prevention, detection and protection measures at the site were commensurate with those that would be expected for a similar sized installation storing normal combustible material. On a qualitative basis this would ensure the risk was satisfactorily controlled when relevant best or good practice is adopted.

The method of comparing the relative toxicity of the proportion of parent material entrained into the fire plume to that of the proportion of carbon monoxide or hydrogen chloride generated from the material and packaging could be used to indicate if a more rigorous assessment were needed. Caution would be required where materials containing high proportions of nitrogen, nitrile or cyanide species were being stored which could significantly increase the proportion of hydrogen cyanide generated.

(1) Health and Services Advisory Committee, *Safe Disposal of Clinical Waste,* HSAC, 1999.
(2) The Control of Major Accident Hazard (COMAH) regulations 1999
(3) Fire Statistics United Kingdom 1987. 22- page 8 HMSO
(4) Halpin, B.M. and Berl, W.G., "Human Fatalities from Unwanted Fires," Report NBS-GCR-79-168, U.S. National Bureau of standards, Washington, DC, 1978
(5) Harland, W.A. and Woolley, W.E., "Fire Fatality Study," Building Research Establishment Information paper, University of Glasgow, IP18/79, Glasgow, Scotland.
(6) Weger, D.d., et al., TNO Contribution to the CEC STEP Programme CT-90-0096"Major hazards arising from fires in warehouse and chemical stores",. 1995, TNO Institute of environmental science: Apeldoorn
(7) Private communication with Dr. M Holiday, Freeman Laboratories (Pathology) Department of Microbiology, Freeman Hospital Newcastle Upon Tyne.
(8) Atkinson, G.T. S.F. Jagger and P.G. Kirk. *The Assessment of Individual Risks from Fires in Warehouses containing Toxic Materials*. Health and Safety Executive Research Laboratory Services Division, Harpur Hill Buxton UK
(9) Atkinson, G.T. S.F. Jagger. *Assessment of hazards from warehouse fires involving toxic materials*. Industrial fires. 1993. Apeldoorn The Netherlands: Commission of the European Communities Directorate General XII.
(10) Turner, R.M. and S Fairhurst., Assessment of the toxicity of major hazard substances, , HSE, Specialist inspector report No 21, May 1989, HSE Information services.